QUALITY CONTROL AND ACCEPTANCE

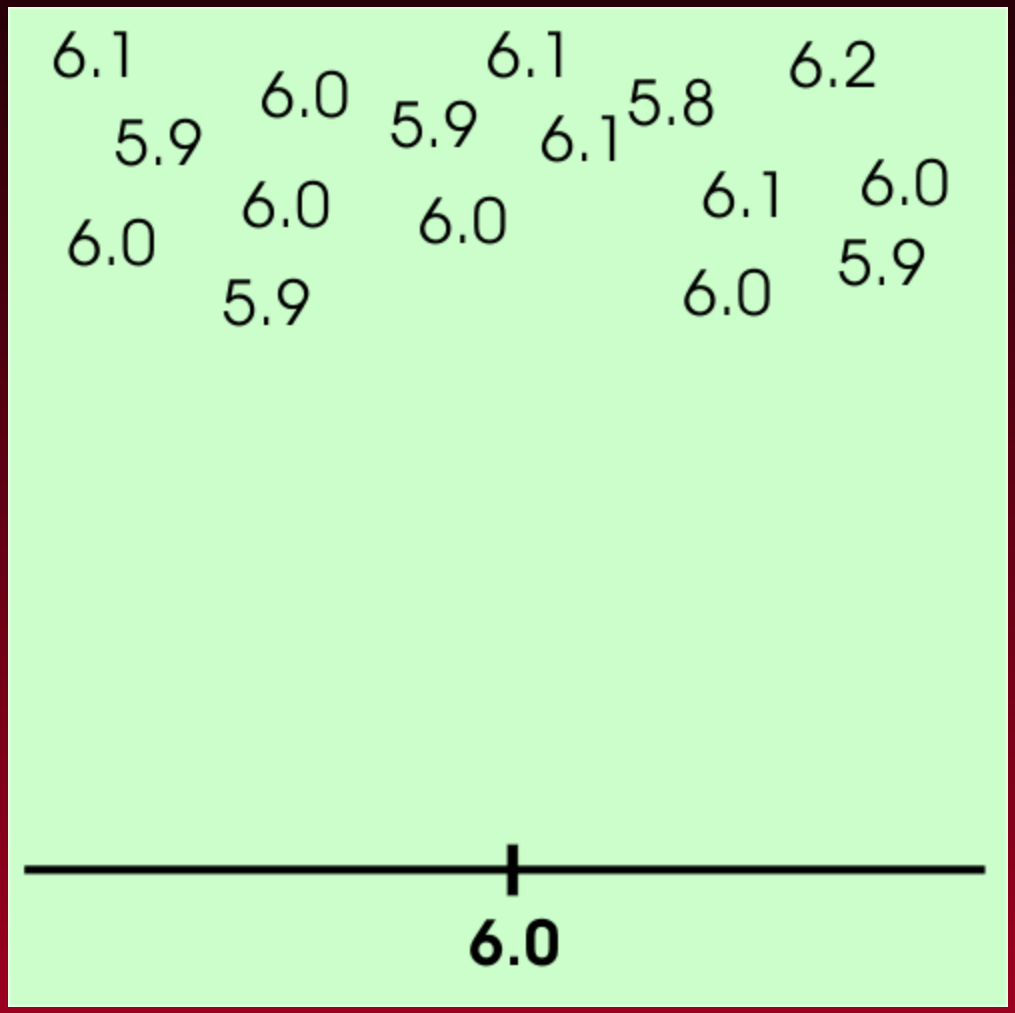
STATISTICAL PROCEDURES BASED ON PERCENT-WITHIN-LIMITS (PWL)

PWL OVERVIEW

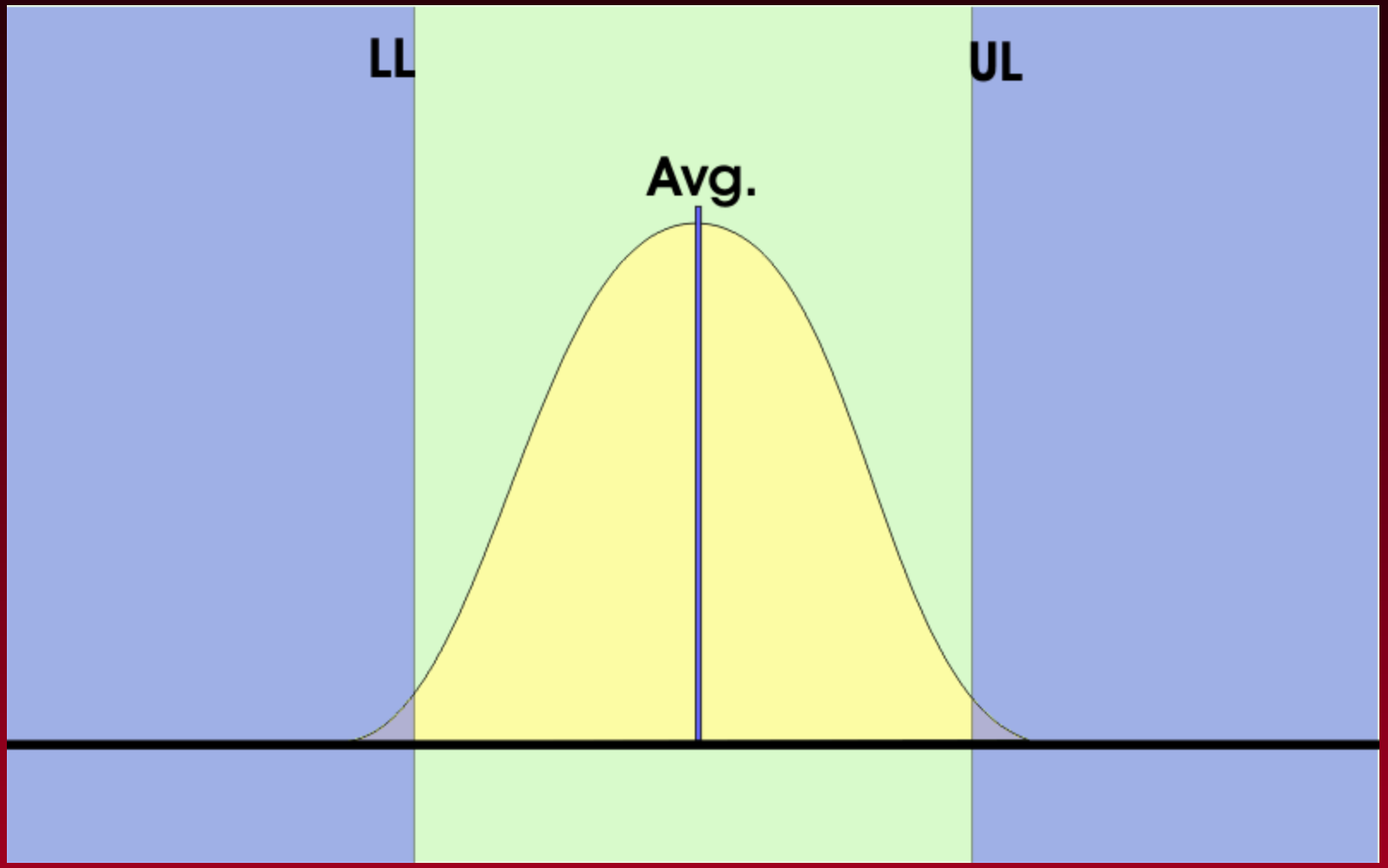
Percent-Within-Limits is a statistically-based method to estimate the percentage of a “lot” of material that falls within the required specifications.

A basic assumption is that the test values follow a normal distribution. The method then incorporates both the sample mean and standard deviation to estimate PWL.

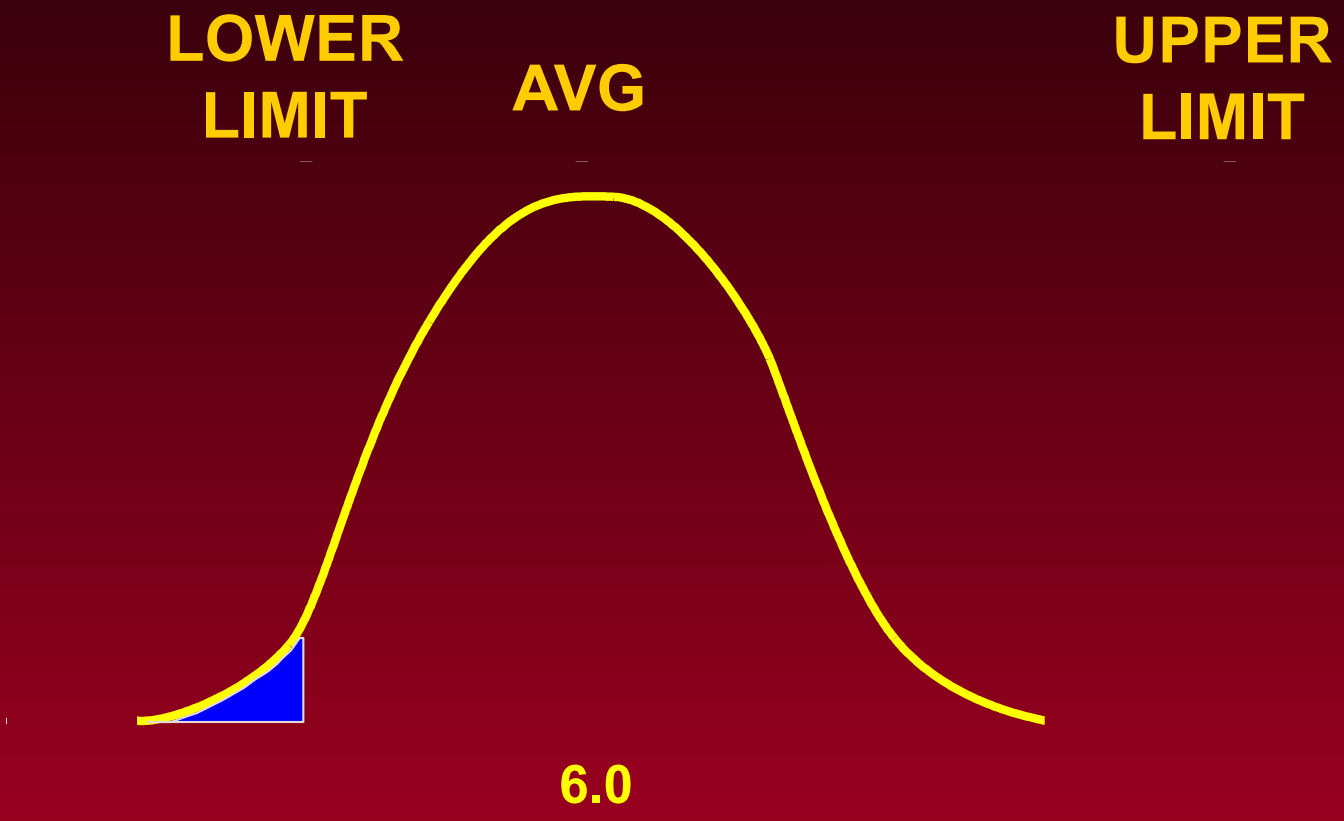
A Normal Distribution naturally occurs as specific values are targeted, but not always hit



Past QC specifications have required that the average of the tests within a lot remain within certain limits



ODOT's Percent Within Limits specification allows only 10% of the lot to be outside the limits for 100% pay



ODOT's PWL spec has 3 main components:

- Initialization Testing
- PWL Calculations
- Control Charts

PWL CALCULATIONS

GENERAL INFORMATION

ASPHALT

- ✔5 Sublots per lot
- ✔Sublot size - 1,000 Tons
- ✔Lot size - 5,000 Tons
- ✔When Lot contains 3 or less sublots, combine w / previous lot

QUALITY CHARACTERISTIC	LOWER* *SPEC* LIMIT (LSL)	UPPER* *SPEC* LIMIT (USL)
ASPHALT CEMENT CONTENT	JMF - 0.4 %	JMF + 0.4 %
AIR VOIDS (LAB-MOLDED)	JMF - 1.35 %	JMF + 1.35 %
ROADWAY DENSITY	91.5 %	97 %

* Special Provision 411-9QA(a-ap) 99

QUALITY CHARACTERISTIC	LOWER* *TARGET* LIMIT (LTL)	UPPER* *TARGET* LIMIT (UTL)
ASPHALT CEMENT CONTENT	JMF - 0.16 %	JMF + 0.16 %
AIR VOIDS (LAB-MOLDED)	JMF** - 0.75 %	JMF** + 0.75 %
ROADWAY DENSITY	93 %	96 %

* Special Provision 411-9QA(a-ap) 99

GENERAL PROCEDURE

STEP 1

- ✔Calculate Mean (X) for lot
- ✔Calculate Standard Deviation (S') for lot

EXTREME VALUES (OUTLIERS)

Apparently inconsistent results will be analyzed in accordance with ASTM E 178 (upper 2.5% significance level).

Test results determined not representative will be discarded. The remaining test results *may* be supplemented.

GENERAL PROCEDURE

STEP 2

✔Check conditions for target-adjusted Standard Deviation (S”)

✔If necessary, calculate S”

GENERAL PROCEDURE

STEP 3

- ✔Calculate Lower Quality Index (Q_L)
- ✔Calculate Upper Quality Index (Q_U)

GENERAL PROCEDURE

STEP 4

- ✔Using the number of observations, the quality index, and the appropriate table, find the Percent Defective (PD)
- ✔For a two-sided specification:

$$PD = PD_L + PD_U$$

GENERAL PROCEDURE

STEP 5

✔Calculate Percent Within Limits (PWL)

PWL = 100 - PD

Note: If PWL < 50 %

-May be required to remove and replace entire Lot for that Quality Characteristic

-Lot may be subject to 0 % Pay

GENERAL PROCEDURE

STEP 6

✔Calculate Pay Factor for each Quality Characteristic

$$PF = 0.024(PWL) - 0.0001(PWL)^2 - 0.35$$

Note: If PWL = 100, PF = 1.05

Note: If PWL = 90, PF = 1.00

GENERAL PROCEDURE

STEP 7

✔ Calculate Combined Pay Factor (CPF)

$$CPF = \frac{5PF_D + 3PF_V + 2PF_A}{10}$$

where: CPF = Combined Pay Factor,
PF_D = PF for Roadway Density,
PF_V = PF for Air Voids, and
PF_A = PF for Asphalt Content.

GENERAL PROCEDURE

STEP 8

✔Calculate Pay Adjustment (PA)

$PA_{Lot} = (CPF-1)(CUP)(Q_{Lot})$

where: PA_{Lot} = Pay Adjustment for Lot,
CPF = Combined Pay Factor,
CUP = Contract Unit Price, and
Q_{Lot} = Quantity of material in Lot.

OTHER PAY ADJUSTMENTS

- Smoothness (if required)

These adjustments will be completely independent of PWL adjustments. The total pay adjustment for the entire project is the sum of:

- PWL
- SMOOTHNESS
- ANY OTHER

EXAMPLE # 1

ASPHALT: % Air Voids

LOT / SUBLOT	% AIR VOIDS
2 / 1	4.7
2 / 2	4.8
2 / 3	5.8
2 / 4	4.9
2 / 5	5.1

STEP 1 - X AND S'

L / S	% AIR	X	(X_i-X)	$(X_i-X)^2$
2 / 1	4.7	5.06	-0.36	0.1296
2 / 2	4.8	5.06	-0.26	0.0676
2 / 3	5.8	5.06	0.74	0.5476
2 / 4	4.9	5.06	-0.16	0.0256
2 / 5	5.1	5.06	0.04	0.0016
	$\sum$ = 25.3			$\sum$ = 0.7720

$$X = \frac{\sum X_i}{N} = \frac{25.3}{5} = 5.06$$

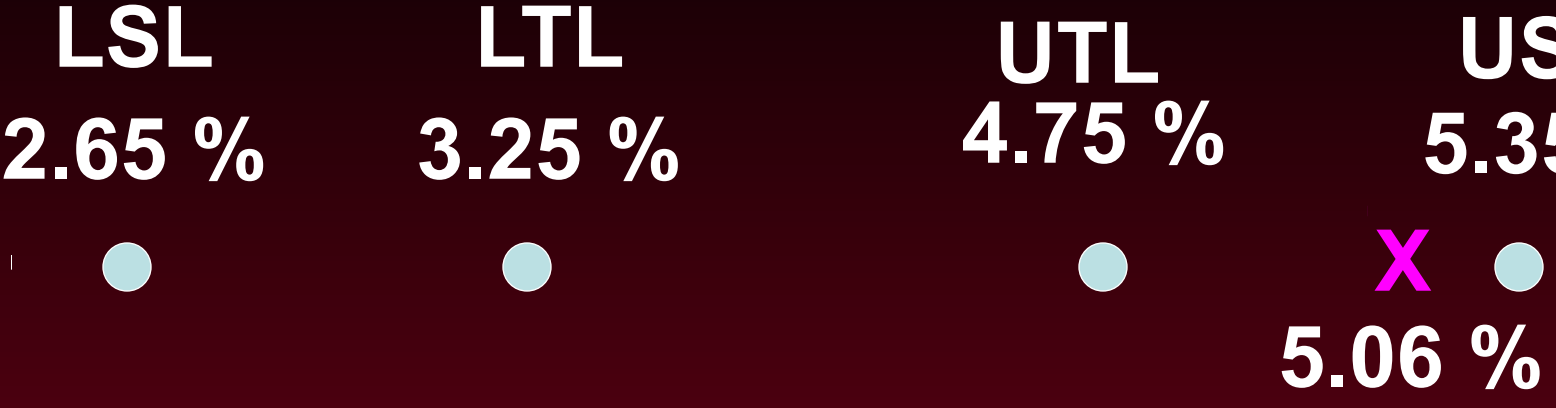
FINISH CALCULATING S’

$$S' = \sqrt{\frac{\sum_{i=1}^{n} (X_i - X)^2}{n - 1}}$$

$$S' = \sqrt{\frac{0.7720}{5 - 1}}$$

$$S' = 0.43932$$

STEP 2 - CHECK CONDITIONS




```
LSL = 4 - 1.35 = 2.65
LTL = 4 - 0.75 = 3.25
UTL = 4 + 0.75 = 4.75
USL = 4 + 1.35 = 5.35
```

X is outside Target Limits and inside Specification Limits, so compute S”

STEP 2 - CHECK CONDITIONS (Compute S")

$$S'' \hat{=} \sqrt{S'^2 + (X_{target} - X)^2}$$

$$S'' = \sqrt{0.43932^2 + (4.75 - 5.06)^2}$$

S" = 0.53768

Note: Had X been within target limits, LTL to UTL, or outside the specification limits, X < LSL or X > USL then: S" = S' (S" computation not needed)

STEP 3 – CALCULATE Q_L AND Q_U

$$Q_L = \frac{X - LSL}{S''} = \frac{5.06 - 2.65}{0.53768} = 4.482$$

$$Q_U = \frac{USL - X}{S''} = \frac{5.35 - 5.06}{0.53768} = 0.539$$

STEP 4 - FIND PD

SAMPLE SIZE N = 5

$Q_L = 4.482$

	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
4.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$Q_U = 0.539$

0.4	35.19	34.85	34.50	34.16	33.81	33.47	33.12
0.5	31.76	31.42	31.08	30.74	30.40	30.06	29.73
0.6	28.39	28.05	27.72	27.39	27.06	26.73	26.40

STEP 4 - FIND PD

INTERPOLATE VALUES

1) 31.42 – 31.08 = 0.34

2) 0.34 / 10 = 0.034

3) 0.034 x 9 = 0.306

4) 31.42 – 0.306 = 31.114

$PD_L = 0.00$

$PD_U = 40.535$

$PD = PD_L + PD_U = 0.00 + 31.114 = 31.114$

STEP 5 - CALCULATE PWL

PWL = 100 - PD

= 100 – 31.114

= 68.886

STEP 6 - CALCULATE PAY FACTOR

$$PF_V = 0.024(PWL) - 0.0001(PWL)^2 - 0.35$$

$$= 0.024(68.886) - 0.0001(68.886)^2 - 0.35$$

$$= 0.829$$

STEP 7 - CALCULATE COMBINED PAY FACTOR

$$PF_D = 1.015^* \quad PF_V = 0.829 \quad PF_A = 1.007^*$$

$$CPF = \frac{5PF_D + 3PF_V + 2PF_A}{10}$$

$$= \frac{5(1.015) + 3(0.829) + 2(1.007)}{10}$$

$$= 0.9576$$

* Example value

STEP 8 -CALCULATE PAY ADJUSTMENT

CPF = 0.9576

CUP = $75.00 (example)

Q_{Lot} = 5000 TONS (example)

$$PA_{Lot} = (CPF-1)(CUP)(Q_{Lot})$$

$$PA_{Lot} = (0.9576-1)(\$75.00)(5000)$$

$$PA_{Lot} = -\$15,900$$

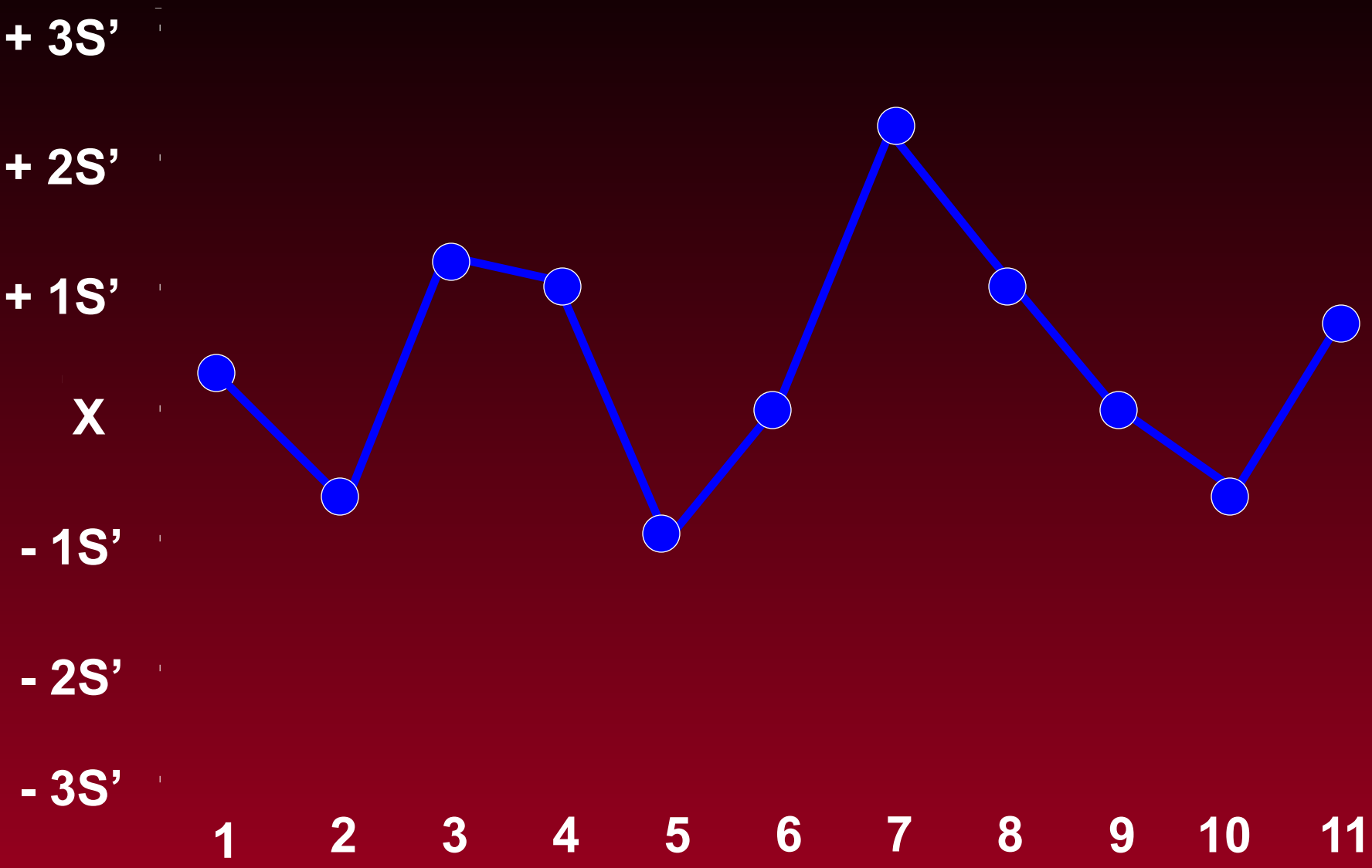
CONTROL CHARTS

- ✓ PROVIDES A VISUAL METHOD TO AID IN THE CONTRACTOR'S PROCESS CONTROL

TWO TYPES ARE REQUIRED

The first centers the mean on the y-axis and plots the test results showing one, two, and three standard deviations from the mean. This chart is meant to clearly show the process variability.

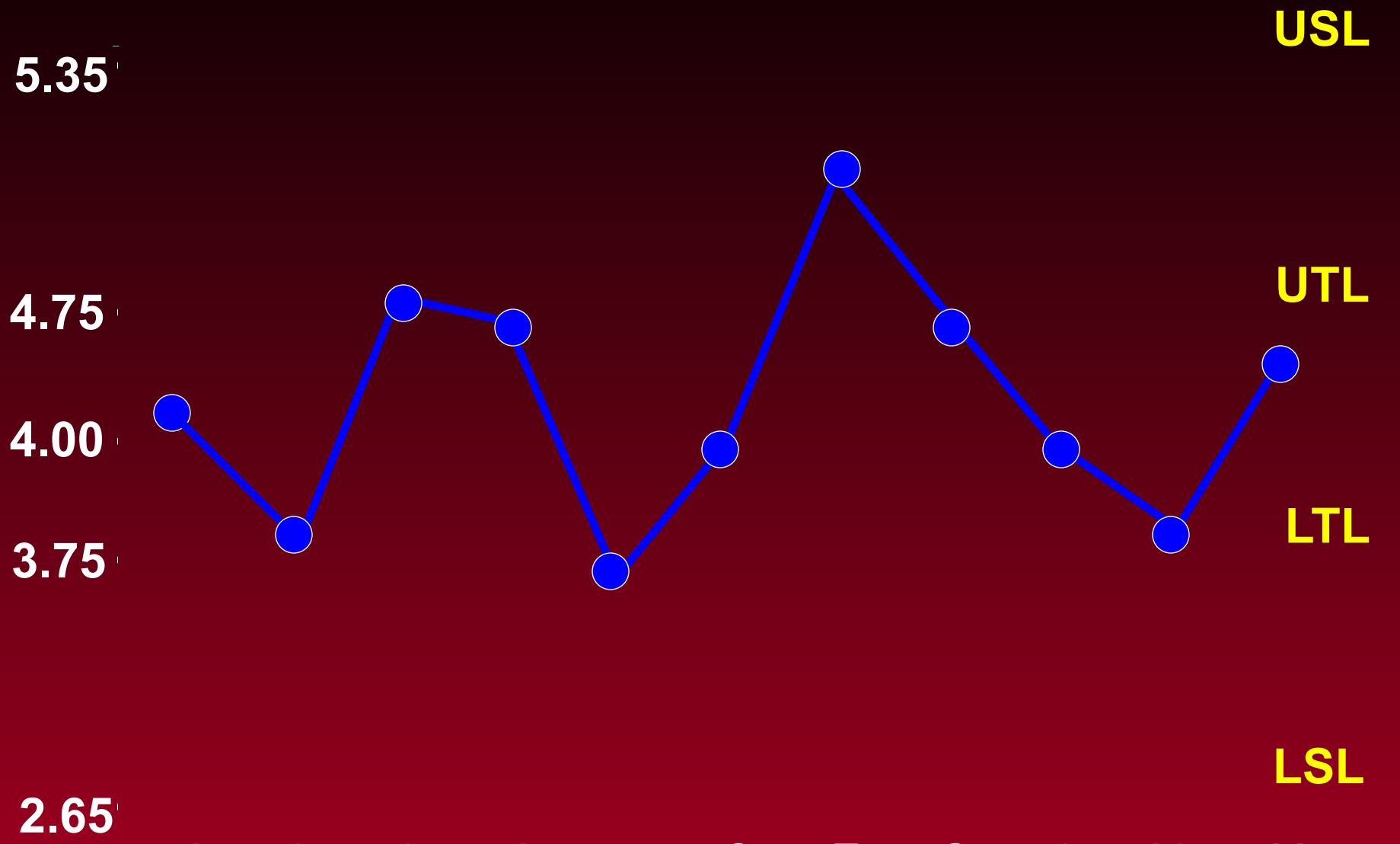
PERCENT AIR VOIDS



TWO TYPES ARE REQUIRED

The second plots the test results against the target and specification limits. This chart is meant to clearly show the process accuracy.

PERCENT AIR VOIDS



OUT-OF-CONTROL CONDITIONS

1. Any one point is more than 3 SD's from the centerline
2. Nine points in a row are on the same side of the centerline
3. Six points in a row are all increasing or all decreasing
4. Fourteen points in a row are alternating up and down
5. Two out of three points are more than two SD's fron the centerline (and on the same side of the centerline)

OUT-OF-CONTROL CONDITIONS

6 Four out of five points are more than 1 SD from the centerline (and on the same side of the centerline)

7 Fifteen points in a row are all within 1 SD of the centerline

8 Eight points in a row are all more than 1 SD from the centerline (on either side of the centerline)

Contractor must provide written notification to ODOT within 18 hours if any of alarm conditions 1, 2, 3, 5, 6, or 8 are observed.

Contractor must provide written notification to ODOT within 36 hours concerning the investigative / corrective actions taken.

Failure to provide written notification within the specified time period will result in an automatic 0.5% reduction in the composite pay factor for the lot affected.